DISLOCATION MOBILITY IN COPPER AND ZINC AT 44°K*

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The torsion technique for dislocation mobility studies in close-packed metallic crystals developed by Pope, et al. (1) was first extended to low temperatures by Gorman, et al. (2). With this method, dislocation displacements are observed by x-ray diffraction on a crystal surface which was previously bonded directly to the torsion machine. Therefore a bonding agent must be utilized which is sufficiently strong to transmit the torsional stress pulse but pliable enough to prevent damage to the very soft test crystal. Various mixtures of organic solvents were found to have suitable properties when cooled to their glass-transition temperatures, and with these bonding agents mobility experiments were extended down to 66°K (2, 3, 4, 5). The torsion tests were carried out in an apparatus in which the test crystal could be cooled to any temperature down to the freezing point of nitrogen.

Recently the apparatus was modified to increase the range of measurements to 4.2°K. A schematic diagram of the equipment is shown in Fig. 1. A long rod of steel or titanium, of 1.27 cm diameter, extends from the torsion machine into a moveable liquid helium cryostat. The rod is fitted with semiconductor strain gages to record the loading and unloading torsion waves. The rod is also fitted with a test section by means of aligning bearings. The test section is supported externally by support bearings and compression springs, and may move vertically along the torsion rod. Its position is fixed by the setting on the micrometer. The test crystal sits on the aligning plate which is screwed into the bottom of the test section.

Helium gas acts as the heat transfer medium between the cryostat and test crystal. The rate of cooling of the test crystal and the minimum temperature reached (below 77°K) are controlled by the flow rate of the transfer gas and the

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level of liquid helium in the cryostat.

The low-temperature bonding agent is extremely volatile and therefore is not introduced into the gap between the test crystal and torsion rod until the crystal is cooled to about $100^{\circ}K$. The procedure is as follows: The crystal is loaded into the test section, and the cryostat, filled with liquid nitrogen in the outer jacket only, is raised up around the equipment. The test crystal is subsequently cooled to about $100^{\circ}K$, then the cryostat is lowered, the plug is removed from the small hole in the test section, and the bonding agent is introduced through this hole onto the crystal's top surface. With the aid of the micrometer the test section is carefully raised so as to reduce the gap between crystal and torsion rod to about 0.005cm. Then the plug is reinserted and the cryostat raised for a second time. Liquid helium is introduced into the cryostat when the test crystal has been cooled to about $90^{\circ}K$.

When the bonding agent has been cooled to its glass-transition temperature, it is sufficiently viscous to support the weight of the test crystal, so the test section is lowered away from the crystal, again using the micrometer. Subsequently the torsion machine is fired and a loading torsional wave propagates down the torsion rod, is reflected from the free end of the crystal, and finally propagates vertically upward as an unloading wave.

Mixtures of various organic solvents were tested for their glass transition temperatures. Liquid propane and isopentane, in a volumetric ratio of 10:1 proved to be adequate at $44^{\circ}K$. Initial attempts to find a suitable bonding agent for a lower temperature were unsuccessful.

Copper and zinc test crystals in the form of cylinders 1.27 cm in diameter and approximately 1 cm long, were prepared as in previous work (4, 5) and then tested in the torsion apparatus. Measurements of edge dislocation displacement versus distance from the cylindrical axis of the crystal, r, are shown in Fig. 2 for one test on copper. For zinc it was possible to draw straight line asymptotes for dislocation displacement as a function of this radius, r, directly from the Berg-Barrett x-ray topographs. We note that, also in copper, dislocation displacement is linearly proportional to r. The displacement versus radius data was converted, as in (5), to damping coefficients for copper and zinc at 44°K. These are presented in Table I, and are shown with higher temperature values of B in Fig. 3.

TABLE I

Values of the Dislocation Damping Coefficient B for Edge Dislocations in Copper and Zinc at 44°K

Material	Damping Coefficient, B 10^{-5} dynes sec/cm^2
Copper	3.26
Zinc	3.63

We recall that in previous low-temperature work in copper (5), dislocation velocity was found to be slightly non-linearly dependent on stress, with a mobility coefficient, n, between 1.0 and 1.14 determined experimentally. However, we now feel that this non-unity value of n was not a measure of a simple lattice damping mechanism, but rather that the particular combination of applied torsion stress (in the range 10^6 to 10^7 dynes/cm^2) and forest dislocation density (4.0 to 4.5x10^4cm/sec) in the test crystals placed the mobile dislocations in the critical region where forest dislocations aid in damping dislocation motion. This effect was predicted by Frost and Ashby (6) and verified recently by Nagata and Vreeland (7) in their experiments. We were careful, in the present experiment, to employ copper crystals with considerably lower forest densities (3.0 to 3.5x10^3cm/cm^3).

The current results in copper agree with those of indirect measurements which indicated that the drag coefficient is a decreasing function of temperature (8). The measurements in both copper and zinc at 44°K are supportive of a model for dislocation damping based on a dissipative force decreasing in magnitude as temperature is lowered. The results are inconsistent with the electron viscosity model for dislocation damping and the experimental results which support that behavior (9).

References

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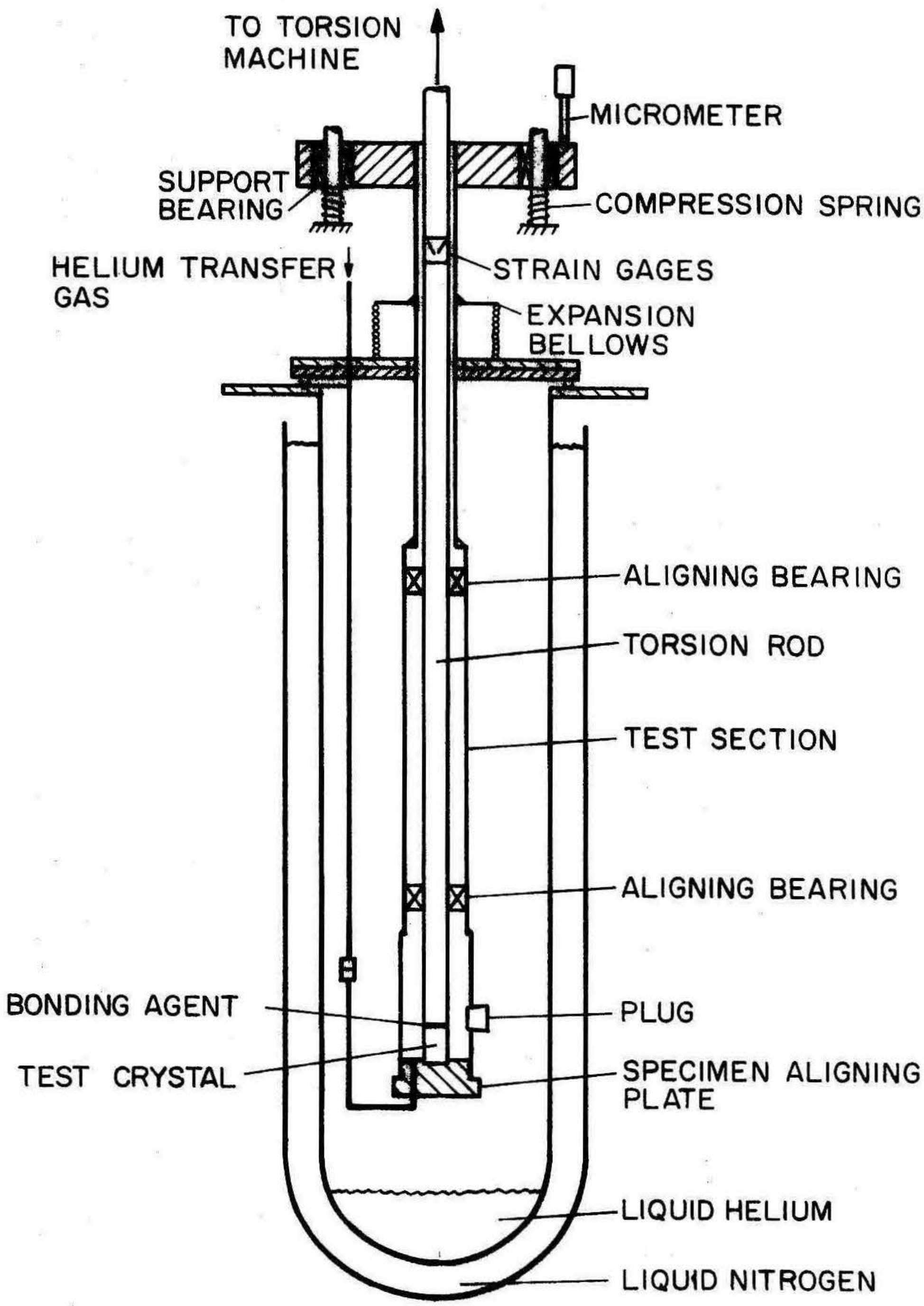

Fig. 1 Schematic diagram of the low-temperature testing apparatus.

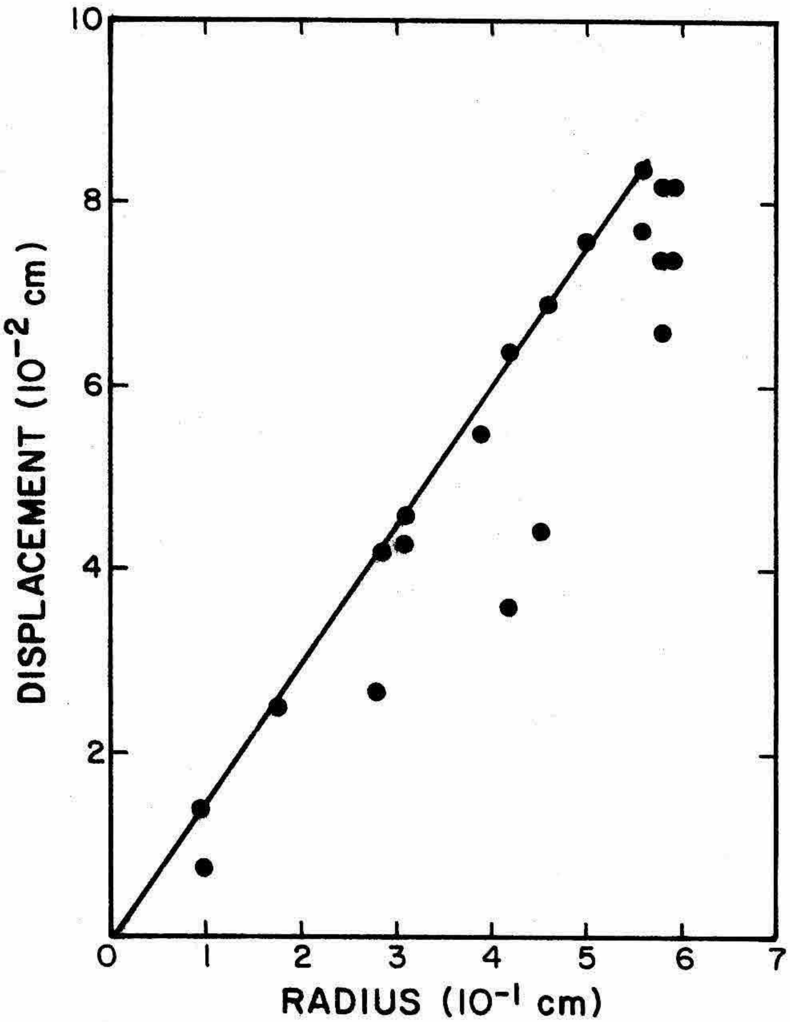

Fig. 2 Edge dislocation displacement as a function of radial distance from the cylindrical axis of a test crystal, for copper at 44°K.

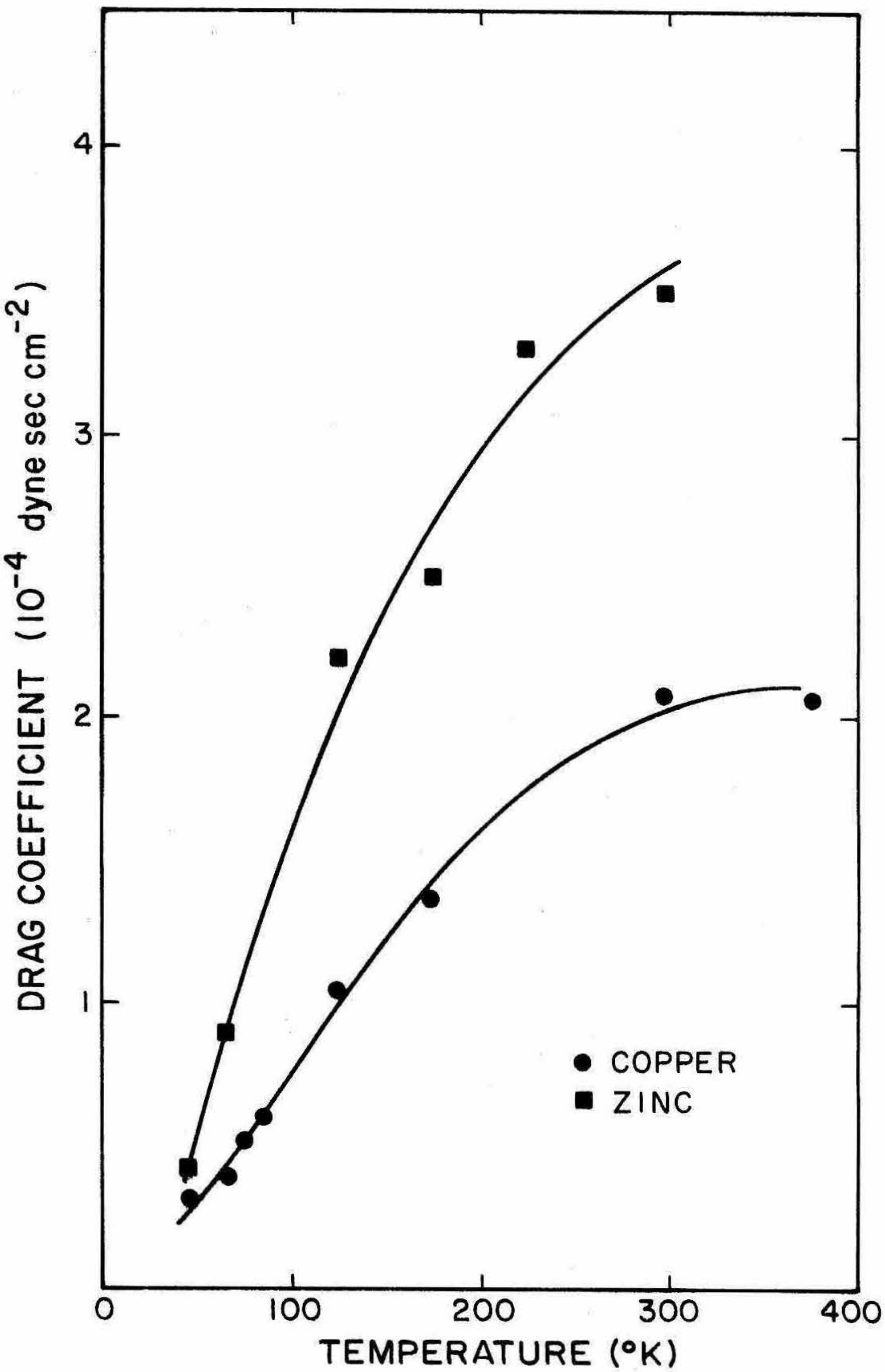

Fig. 3 Dislocation damping coefficient for edge dislocations in copper and zinc as a function of temperature.